

Review

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A review of the chemical and biological pollutants in indoor air in hospitals and assessing their effects on the health of patients, staff and visitors

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Abstract: Indoor air quality in hospitals has been specifically considered in terms of its impact on health. Air quality is an important risk factor influencing the health of staff and patients who are in contact with indoor air inhaled in hospitals. Over the past two decades, hundreds of studies have been developed to assess pollution in hospital environment. Two hundred and fifty papers from around the world, from the last two decades, were identified and reviewed. Recent studies have found that the presence of various chemical and biological pollutants affected the health of patients, staff and visitors. Nearly all the reports agree that chemical and biological pollutants in the hospital environment have adverse effects. In most of the reviewed papers, analysis of health hazards was conducted for personnel and patients to toxic metals, chlorine, fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particles, and bio-aerosol in the inhaled air of the hospital environment. Some papers showed that some of the metals are carcinogens and others do not have a carcinogenic risk. Bio-aerosols as a biological pollutant are usually defined as airborne bacteria, fungi, viruses, pollen and their by products. These biological pollutants are associated with a wide range of health effects in hospital environments. This review can serve as an introduction and as the statement of the problem for more original research in this regard.

Keywords: biological pollutants; chemical pollutants; hospital; indoor air; pollutants.

Introduction

The quality of the indoor air in hospitals has its own complexity and is different from the air quality in residential and occupational environments. The activities of the hospital are around the clock and 7 days a week, so the sources of chemical and biological pollutants and pathogenic agents are continuous (1). Besides the production of pollutants of domestic origin, contaminated airflow from the outside into the hospital causes indoor air quality (IAQ) to be unfavorable in hospitals. This is why desirable air quality is not only critical for patients, but it also negatively impacts hospital staff and their efficiency, which is often neglected in this area (2). Contamination of hospital and health care centers should be considered due to the sensitivity of patients to chemical and biological pollutants. In addition, particles in closed environments carry infectious microbes and microbial metabolites which are found abundantly in health centers (3); hence, there are health risks including airborne infectious disease transmission (4–6). The environment can affect the incidence of many types of cancers as well as chronic diseases and disabilities (1). Natural and artificial materials in the environment and other environmental factors play very important roles in the incidence of different cancers in human beings (2). Based on the evidence from the last 20 to 30 years, chronic diseases such as asthma have increased in children and adults (7, 8); as a result, concerns about potential environmental risks are increasing (9). Different factors can increase the likelihood of chronic diseases. This possibility is probably due to the existence of one causative agent and the effect of other intensifying factors (1). For example, exposure to chemical agents in the environment, known as environmental risk factors for the development of chronic diseases in children, can play a role in the development of diseases such as asthma, obesity, behavioral disorders and learning problems in children (7). For this reason, the role of chemical agents in the environment as risk factors for many chronic diseases have been increasingly considered (9). Hospital infections

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are a global issue, so many studies have examined the amount, source and characteristics of bio-aerosols in hospitals (10–13). According to their studies in 37 hospitals in Thailand in 2015, Chien-Cheng Jung et al. reported that carbon dioxide (CO₂) and total volatile organic compounds (TVOC) rates are higher in hospital wards and pharmacies than in other parts of hospitals due to the existence of treatment activities and medicines, as well as the lack of proper ventilation (14). According to studies by Bessonneau, ethanol, isopropanol, acetone and ether are higher in hospital wards than in other parts of the hospital (15). Lo et al. found that aromatic hydrocarbons are more frequently found in pharmacies than in other parts of hospitals (16). Public awareness about the health risks associated with undesirable IAQ in closed environments is increasing (17–19). Because patients spend most of their time in closed environments (20), long-term exposure to pollutants in indoor air can intensify their adverse effects and health hazards (21). Among these pollutants, most researchers have focused on the inhalation of very fine particles (PM_{2.5}) (25), considered important in acute and chronic respiratory illness and cardiopulmonary effects, such as lung cancer (26, 27). Hence, medications, therapeutic procedures, cleaning and disinfection can also affect the IAQ in hospitals. Therefore, it is necessary to examine the characteristics of biological and non-biological pollutants in hospitals. Recent research has proved that the characteristics and distribution of IAQ in hospitals can be altered due to medical activities and materials in different workplaces (10, 28).

The objective of this review was to consider the role of hospitals in promoting a community's health and the specific sensitivities; studies on chemical and biological pollutants in such places were evaluated separately.

Our aim is to provide an overview of the evidence in the literature on indoor air pollution in hospitals and their effects on patients and staff. Therefore, in this descriptive review, a total of 250 papers were identified that fitted the inclusion criteria for this study. Of these, 117 articles were selected for review. All these reviewed papers were conducted in the last two decade from around the world.

Search strategy

The literature search of the databases Medline, Pubmed, ScienceDirect, Google scholar and Web of Sciences was completed for articles published until Jun 2017. The studies related to hospital pollutants and their effects on the health of patients, staff and visitors, for both biological pollutants and non-biological pollutants were selected

from these databases. The language of the searched articles was English. After unsuitable or less valuable articles were removed the remaining ones were searched by titles, abstracts, and full text, respectively. If the title and abstract were interesting, the full text was retrieved and reviewed. The literature search was conducted using pre-determined keywords. A search was made for keywords: hospital, pollution, pollutants, indoor air, biological pollutants, chemical pollutants, hospital assessment, health effects, patients, staff, visitors, bio-aerosol, hospital infectious, hospital risk assessment and a combination of these keywords. A total of 463 articles were collected. After screening, 117 articles fit the criteria for inclusion. We checked the reference lists of the reviewed articles for additional references.

Hospital pollutants

Hospital personnel and visitors are in direct contact with various types of pollutants in medical environments. Inhalation is the most common type of contact that is often neglected by the general public. Hospital pollutants existing in health and medical environments can be divided into two general categories of biological and non-biological pollutants that are described in the following sections.

Biological pollutants

A review of 26 studies, in 2011 in Australia, and a Portuguese urban hospital in 2012, indicate that particles can carry pathogens that increase the risk of respiratory infections (13, 29). Studies in 2009 and 2015 in hospitals in London, indicate that air conditioning systems are installed to provide heat, ventilation and air conditioning (HVAC), mechanical ventilation in hospitals can also control IAQ. Appropriate and proportional control of air filtration is an important factor in controlling indoor and outdoor pollutants that can easily transfer airborne respiratory microorganisms through these systems (5, 30). In the HVAC systems in 20 operating rooms in 10 hospitals in Athens and Egypt, which did not function properly, these microorganisms were found, due to the inadequate maintenance of these HVAC systems. Recently, it has been reported (30) that among ten hospitals in London, only four hospitals comply with the European standard for air filters (31, 32). Good performance of ventilation systems is also considered in controlling pathogens in hospital environments.

Studies in Pakistan, Iran and Turkey in 2012, 2015 and 2015, respectively, in indoor urban environments showed that bio-aerosols are a major category of airborne aerosols that enter human body through inhalation and ingestion, and significantly influence human health (33, 34). Probably the two major categories of bio-aerosols are fungal spores and bacteria (35), which typically have a diameter of about 1–30 μm and 25 μm (25 μm), respectively (36). Additionally, a study in northeast Brazil on the air in two public hospitals in 2010 and a survey in hematological unit in a French hospital in 2009, indicated that bio-aerosols aggravate infectious diseases such as asthma, allergies and neurological diseases (37). Mycotoxins produced by fungi have a negative effect on human health, which can cause respiratory and digestive problems (37, 66).

Bio-aerosols enter the air from various natural and artificial sources such as soil, plants, people, animals, sewage treatment and agricultural activities. Although airborne microorganisms originate from different sources, no relative significance or difference in their characteristics have so far been recognized (39). When a particle is inhaled and deposited in respiration region, the effect of that bio-aerosol particle depends on its size. The particle deposition region depends on the size and composition of the particle, which are linked to the particle's hygroscopic properties (40). Larger aerosols ($D_p > 5 \mu\text{m}$) generally affect the upper part of the respiratory system and cause allergic reactions (34) while smaller aerosols, especially in sizes smaller than 1 μm , can penetrate the alveolar region in the deepest parts of the lung and cause adverse effects. Important and different factors affect the concentration and composition of bio-aerosols in the environment, such as dust retention, internal sources of pollution, plants, temperature, humidity, ventilation and air exchange (33, 41). Although often originating from outdoors, there are different dangerous combinations that can cause bio-aerosols in hospital environments, including indoor activities such as heating, ventilation and air-conditioning (HVAC) (42). According to these studies, bio-aerosols either originate from outdoor and indoor activities in hospitals especially, that could have a negative effect on health.

Non-biological pollutants

Besides biological pollutants, studies indicate that non-biological and chemical pollutants, potentially effect health. Personnel working in medical environments are exposed to a wide range of non-biological and chemical pollutants (organic and mineral compounds). In a study at an educational hospital in France, based on sampling

from six areas of the hospital, the main organic compounds found in hospital air included alcohol (ethanol and isopropyl alcohol), ether (diethyl ether) and ketone (44). The concentration of chemical compounds in hospital air is determined by the medications used in the hospital environment (44). This is an important stage in screening the risk not mentioned in most scientific studies (44). The relationship between airborne particles of less than 2.5 μm ($\text{PM}_{2.5}$) in indoor environments and their adverse effects has been widely studied. Recent scientific information from a US hospital study confirmed the relationship between $\text{PM}_{2.5}$ and the mortality risk in all cases of illness (44). The health effects of $\text{PM}_{2.5}$ are not only a function of their concentration and size but also depended on the components and compounds associated with them, such as carbon black, toxic metals and organic particles (45–47). Black carbon (BC) particles are an indicator of incomplete combustion. This pollutant flows from outdoors to indoors (48). In hospital environments, these particles ($\text{PM}_{2.5}$) are associated with many chemical substance being inhaled.

In a hospital radiology department in an urban area of Portugal, in 2012, the concentration of particles was measured in two categories of ($\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$) and elemental compounds (24-h impactor sampling). The results of this study showed that indoor PM_{10} concentrations ranged from 13 to 58.8 $\mu\text{g}/\text{m}^3$ and from 10.5 to 41.9 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$ and the sulfur element was higher than other elements while nickel, chromium, arsenic and lead in fine particles ($\text{PM}_{2.5}$) are higher as compared with coarse particles ($\text{PM}_{2.5-10}$) (29). Also, the study found that health care workers are more likely to develop cancer, due to a lot of contact with these pollutants (more than 8 h), based on the pollutant ratio (concentration and composition of the elements) indoors as compared with outdoors (I/O), which is alarming (29, 43). In most cases, it occurred in health care workers and patients who remained for long time in hospital, thus indoor pollutants can affect these persons.

Another study in the Philippines in four parts [natural ventilation in the pediatric ward and pharmacy, mechanical ventilation in the intensive care unit (ICU) and the Maternity critical care unit (CCU)], (24-h impactor sampling) in two different seasons showed that the mean $\text{PM}_{2.5}$ concentration was between 19.6 (± 7.4) $\mu\text{g m}^{-3}$ to 32.8 (± 7.4) $\mu\text{g m}^{-3}$ (32). In areas with natural ventilation in the hospital, $\text{PM}_{2.5}$ levels were higher than those with mechanical ventilation and the overall mean was higher than the World Health Organization (WHO) 24-h standard (25 $\mu\text{g m}^{-3}$). The ratio of I/O for $\text{PM}_{2.5}$ in all cases was less than 1. The source of most fine particles ($\text{PM}_{2.5}$) is outdoor air. Also, elemental analysis showed that the sulfur content is predominant in

comparison to other elements (32). The ratio of I/O to the concentration of the elements varies in different parts of the hospital; this ratio was more than 1 in Na and Cl in all parts of the hospital (49, 50).

In 2007–2009, another study was conducted in four hospitals in Guangzhou, China to check for $PM_{2.5}$ and PM_{10} indoor and outdoor conditions and various ventilation systems. Elemental components of PM were organic compounds and elemental carbon (EC). Based on the results of the measurements, the concentration of the $PM_{2.5}$ indoor environment was reported as equal to $40.94 \mu\text{g m}^{-3}$ to $214.91 \mu\text{g m}^{-3}$. The mean I/O ratio for $PM_{2.5}$ was between 0.77 and 1.17, depending on the section and ventilation system (52, 53).

The I/O ratio for EC was equal to 0.66 to 1.66 and the mean I/O ratio for rare elements was reported to be less than 1. More than two studies have been conducted with different sampling methods for $PM_{2.5}$ as listed: The first method was used in European hospitals using a manual laser display (Aerocet 531, Met One instrument Inc., USA) and the second method was used in 37 hospitals in Taiwan using the Air Track aerosol monitor (8520 model, USA) (52, 53). Because $PM_{2.5}$ is measured with different devices, the results should be compared with caution due to differences in the type of the device (51, 53, 54). Variation of the I/O ratio in different hospital is not very important but a high level of $PM_{2.5}$ in a hospital is very important due to adverse health effects.

Jung et al. reviewed 37 atmospheric pollutants in 37 hospitals in Thailand, in 2009, which had four different ventilation systems. They reported that human activities in different locations and the type of ventilation system are two very influential factors on air quality. They realized that the filtration system, along with the central air conditioning system could effectively remove fine particles from outdoor air but it could not control the level of CO inside the hospital in such a way that in a building with central air conditioning system, the level of $PM_{2.5}$ measured equalled to $11.9 (\pm 4.1) \mu\text{g m}^{-3}$ and in the building without central air conditioning system, the level of $PM_{2.5}$ equalled to $44.6 (\pm 36.5)$. It was also reported that the concentration of $PM_{2.5}$ varies depending on the activity from $10.3 (\pm 5.1) \mu\text{g m}^{-3}$ at the nursing station to $17.2 (\pm 21.9)$ in the clinic (14, 52). So, surveillance on the proper operation of a central air conditioning system, will help to decrease $PM_{2.5}$ level in the hospital environment.

In one study, the difference in CO_2 indoor and outdoor of all hospital rooms was less than 400 ppm, so it was placed in the category of IDA1 according to standard (31). The amount of CO_2 indoors indicates that the air exchange rate is enough to dilute odors and emitted biological pollutants. But the level of CO_2 indoors cannot be considered

as a reliable evaluator for the quality of indoor air. The concentration of CO_2 indoors depends on the number of people indoors and their metabolic rate, but the source of other indoor pollutants at hospitals may come from medications, the functioning of several devices and infiltration from the outdoor, such pollution-causing ways do not depend on the number of people working inside the hospital confirming the findings by Loupa et al. (55). The $PM_{2.5}$ threshold value for human health is determined as $25 \mu\text{g m}^{-3}$ in 24 h, according to the WHO index (28).

Also, a study in 2016, in a Greek hospital, showed that the mean 24-h I/O for $PM_{2.5}$ concentration in the triage and hospital labs was reported as 0.74–1.11 and 0.67–1.07, respectively (7) which is similar to Loupa Gand et al. in 2016; in the reports of Jung et al. (2015) and Wang et al. (2006) there were differences between the two positions (7, 55). The I/O ratio varies as regards the time and location of sampling at hospital. Wang et al. found that in checking the air of a hospital in Livan, in a place where no patient was hospitalized and the ventilation system was mechanical, the concentration of $PM_{2.5}$ was reported to be 5 times higher than the study of Loupa et al. in 2016 (55). In two other studies where the sampling devices functioned based on light scattering, the concentrations of $PM_{2.5}$ was much less than the results by Loupa et al. in 2016 (56–58). So, due to a variation in the amount of fine particle inside the hospital, measurement of them for control of quality of the inside air is considered.

Jung et al. showed that checking real-time air pollution offers a lot of information about the effects of activities on indoor air pollution in hospitals (56). Figure 1 shows the daily changes in $PM_{2.5}$ and BC and CO_2 concentration in the triage area and a laboratory of a hospital using a light bulb (as a sign of presence in the place). In the a laboratory, during the working time, $PM_{2.5}$ and black carbon concentrations were compared with the triage area. The reason for selecting a laboratory is that it is a place with more active human beings (an average of six people inside) and the functioning of medical equipment (56). On the contrary, a triage area was chosen as a place with less active human activity (usually two people there, a nurse and a patient). Nevertheless, the triage area is seen as a place that is active day and night where patients come in case of accident or emergency, with an average of four people there, while maybe 20 people (most of their relatives) are waiting behind the door. Therefore, the concentration of air pollutants in the triage area should also be measured at night (if the lamp of the presence of people is on). On the contrary, the laboratory has a work time of an 8-h day. The laboratory door closes after 14:15 until the next day and the pollutants in the air are reduced to the lowest possible extent (56).

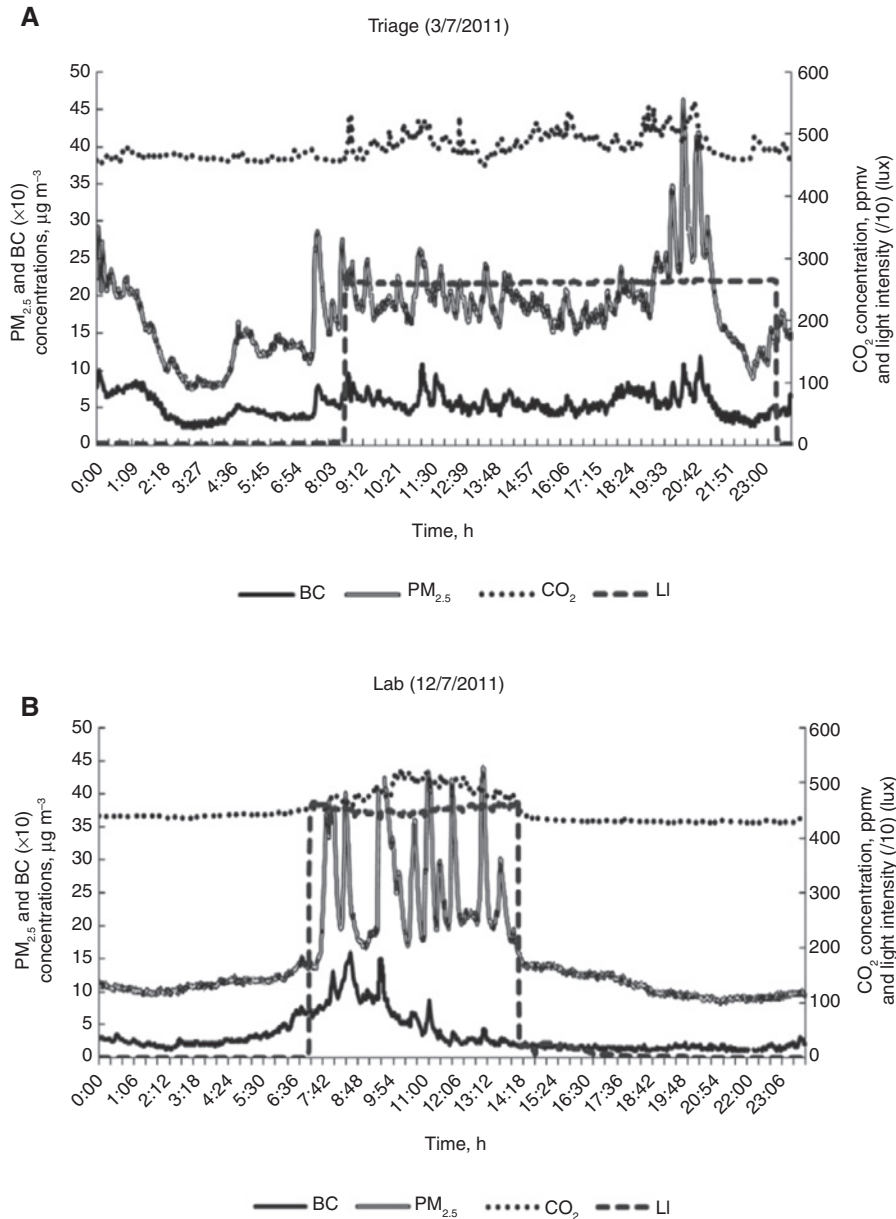


Figure 1: Maximum concentration of daily changes in $PM_{2.5}$ and CO_2 concentration in laboratory in 7:42 am to 14:18 am and triage in about 20 pm (57).

(A, B) Daily changes in $PM_{2.5}$ and BC and CO_2 concentration in the triage and laboratory.

BC does not have an internal origin in a hospital, so it is a rare source of air pollution mostly emitted from the exhaust of diesel engines which later enters hospitals. The BC concentration inside the hospital is a certain percentage of the BC concentration in the outdoor air, which is 90% in the triage area and 73% in the laboratory, although the operating hours in the laboratory are only 8 h day⁻¹. During the night, when the triage area is empty and the doors are closed, the mean $PM_{2.5}$, BC and CO_2 concentration were measured as 12.42 $\mu\text{g m}^{-3}$, 0.51 $\mu\text{g m}^{-3}$ and 472 ppmv, respectively. Similarly, in the laboratory, after 8 h of work and closing the doors, the mean nightly $PM_{2.5}$,

BC and the CO_2 concentration were measured as 10.09 $\mu\text{g m}^{-3}$, 0.46 $\mu\text{g m}^{-3}$ and 467 ppmv, respectively. At the time when nobody was present and the doors and windows were closed, $PM_{2.5}$ and BC inside both places was similar to the outdoor air (7). Pearson's correlation coefficient was $R=0.77$ and $R=0.67$, respectively, which was caused by the influx of airborne outdoor air pollution, indicating an inadequate localized ventilation system that was reported in the operating rooms of a Greek hospital. This study indicates that in public hospitals the ventilation system must be properly operated and periodic control should be considered.

During working hours, $PM_{2.5}$ concentration is affected by several different sources, such as the presence of individuals and their activity (14, 16) and outdoor air coming into by air conditioning system, and the penetration of contaminated outdoor air through open doors in the triage area and closed windows in the laboratory. In hospitals, natural ventilation is not adequate and central air conditioning is essential.

Many hospitals provide increased levels of TVOCs (29) by using disinfection solutions and detergents to reduce hospital infections. Decoration of the building is an important source of TVOC and having a HCHO in the closed space (37, 39, 40). Human activity in a closed environment can affect the amount of PM in the air (42). In addition, outdoor air is another important source of air pollution in the closed environment (59). In recent years in hospitals, the use of different disinfection solution and decoration of the building have increased.

Several studies, in 2007, 2008, 2011 in the USA, have shown that contact with CO, fine particles and ozone can increase the risk of sick building Syndrome (SBS) (60–63), all of them, simultaneously, exist in hospitals.

Also, some studies have shown that contact with volatile organic compounds and hydrogenated organic substances can increase the risk of allergic diseases or cancers (38, 64). Therefore, some studies have also examined IAQ in ICUs and operating rooms in hospitals (34, 38). However, in some articles, IAQ variations are discussed in different parts of the hospital, these changes are based on the fungal source and amount, particles, or TVOC (29, 35, 38, 57).

In recent years, scientists have considered compounds with PM, including elemental carbon, sulfates, nitrates and biological compounds (22–27, 65, 66). Although the precise mechanism of PM health effects is not well known (67), evidence shows the relationship between PM (biological and chemical composition, particle size and reactivity) and its toxicity (25, 67). Therefore, chemical compounds with PM, although a small fraction of particle mass (68, 69), potentially impact its health effects (70). PM has very complex compounds and chemical compounds are one of its important compounds (71) because of toxic properties and the presence of rare-metallic elements in them (71). In indoor environments, the presence of rare elements is due to the penetration of outdoor air into the interior (71, 72) and various internal sources such as wall paint and equipment (73–76). All of these compounds which can be found in hospital environments have adverse effect on human health, hence in the following sections we describe the effects of pollutants in the hospital environment on human health.

Health effects of pollutants in hospital air

In order to assess the health effects of pollutants, it is important to consider the distribution level of atmospheric rare metals as well as other elements (67). Often most toxic metals with anthropogenic origins are found in very small atmospheric particles (77–79). The presence of these toxic metals in very small amounts may be harmless, but many of these rare metal elements and metal compounds are harmful to humans (80).

Hospital indoor air is considered as a special and important public environment (81, 82) a place where poor air quality affects not only the health of the personnel, but also the health of patients (those who have immunodeficiency or those who are sensitive to external factors). Assessing the risk of contaminated air on the health of personnel and patients in such an environment is possible by measuring the airborne particles concentration, including PM and toxins related to them, that so-called rare elements or rare metal ions.

According to studies, unfortunately, information on the amount of PM and metallic elements combined with them in the hospital environment and their health effects on human health is very limited (57, 83) and it is even more necessary now to survey them.

Carcinogenic/non-carcinogenic effects

Carcinogen and non-carcinogen substances are present inside hospitals. So, both must be considered.

Generally, risk assessment consists of four parts. In this assessment, the type of health effects is associated with exposure amount to a chemical known specially as a risk assessment. The evaluation of the relationship between exposure and its effects is called the effective dosage. Assessing the extent of exposure and how it varies depending on the type of application, individuals, and risk characteristics that are associated with exposures amount to effective dosages relative to the estimated risk in the population.

In addition, carcinogenic risk assessment is different from non-carcinogenic risk assessment. It is assumed that there is no safe exposure level for most carcinogens, but when there is no carcinogenic effect, there is a safe exposure level (permissible) exposure dose.

Figure 2 shows different individuals against chemical agents and adverse effects (84).

Carcinogenic and non-carcinogenic effects of rare metal elements assessed by the United States Environmental

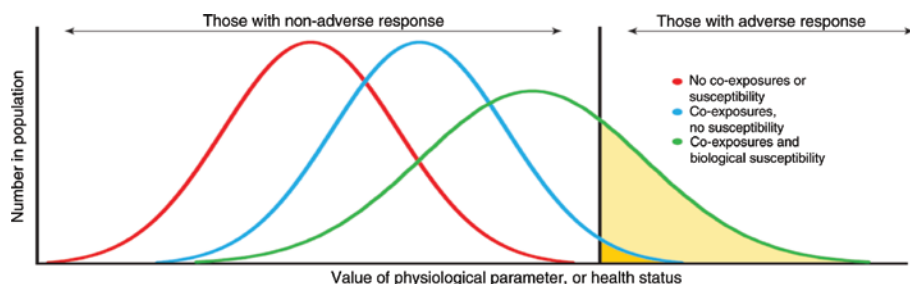


Figure 2: The effect of biological sensitivity and simultaneous exposure to other chemical agents on the relationship between individual chemical exposure and adverse health effects.

Protection Agency (USEPA) based on concentration is presented in Table 1 (85). Reference doses (RfD) are the same during exposure.

To convert the RfD value of oral exposure to the inhalation exposure (ingestion and inhalation exposures) the following equations are used (85):

RfD: reference doses for the same exposure duration

RfC: reference concentration

$$\text{RfD} = (\text{RfC} \times \text{IRA} \times \text{AR}) / (\text{BWA} \times 100)$$

IRA: inhalation rate-adult (20 M³/day)

BWa: body weight, adult (70 kg)

IR: intake rate (100%)

Health effects of PM_{2.5} and PM₁₀ particles

According to studies conducted at hospitals in different countries, the mean PM_{2.5} and PM₁₀ concentrations were measured, which is presented in Table 2 for comparison.

In order to protect public health, it is necessary to consider the standard of air quality in the closed environment in relation to PM_{2.5}. Some experts have suggested that the

IAQ standard should be considered to be 50% or less than USEPA air quality standard (90).

Twenty-one elements were detected in a closed environment using X-ray-stimulated protons (29). Among these elements, 11 elements were evaluated in terms of health risks: Al, Si, Cl, Mn, Se, Ba, Cr, Ni, As, Cd and Pb. Table 3 shows the mean and range of PM_{2.5} and PM_{2.5-10}. Generally, in this study, the mean of these 11 elements in the outdoor environment was between 1.875 and 2.350 μg m⁻³ for PM_{2.5} and 2.570 and 2.620 μg m⁻³. The amount of these elements in a hospital environment was 2 to 3 times lower for PM_{2.5} and 7 to 8 times lower for PM_{2.5-10} (29).

According to a survey in 2005, in Malaysia, among the aforementioned 11 elements, the concentration of Al, Si and Cl in both PM groups was highest. These three elements, respectively, comprise 85–90% of the total concentration of the 11 elements in the PM_{2.5} and PM_{2.5-10} categories. In particular, Cl has the highest concentration in the PM_{2.5} group with 53% of ΣE₁₁, followed by Si with 19% of ΣE₁₁ and finally Al with 13% of the total concentration of 11 elements while in coarse particles, Si with ΣE₁₁ (50%), Cl and Al with 30% and 13%, are the highest, respectively. The presence of Cl in a closed environment may be caused by cleaning and using detergents (91, 92), which are increasingly used in hospitals.

A study in 2011, in Portugal, show that dust from construction materials can cause Cl indoors (93). In the following studies conducted in hospitals located in coastal areas, chloride in indoor air was the result of the penetration of sea salt particles from the outdoors (94). Silicon and aluminum often come from the earth's crust; the granite soil is rich in silicon and aluminum (95). Long-term surveillance of air quality in medical center operating rooms, in Taiwan, in 2011, showed that granite is the most common material used in interior construction. Therefore, the presence of these elements indoors is due to the erosion of internal materials or the penetration of particles from outdoors into the indoor environment (such

Table 1: Material reference dosage for the same time period for 10 metal elements.

| Metal | RfD, mg kg ⁻¹ day ⁻¹ | RfC, mg m ⁻³ |
|-------|--|-------------------------|
| Al | 1.43 × 10 ⁻² | 5.00 × 10 ⁻³ |
| Si | 8.75 × 10 ⁻³ | 3 × 10 ⁻³ |
| Cl | 4.29 × 10 ⁻⁵ | 1.05 × 10 ⁻⁴ |
| Mn | 1.43 × 10 ⁻⁵ | 5.00 × 10 ⁻⁵ |
| Se | 5.71 × 10 ⁻³ | 2 × 10 ⁻² |
| Ba | 1.43 × 10 ⁻⁴ | 5 × 10 ⁻⁴ |
| Cr | 2.86 × 10 ⁻⁵ | 1.00 × 10 ⁻⁴ |
| Ni | 1.43 × 10 ⁻⁵ | 5.00 × 10 ⁻⁵ |
| As | 4.29 × 10 ⁻⁶ | 1.05 × 10 ⁻⁵ |
| Cd | 5.71 × 10 ⁻⁶ | 2.00 × 10 ⁻⁵ |

Table 2: Summary of the literature on comparison of $PM_{2.5}$ and PM_{10} concentrations at hospitals.

| Location and aim of the study | Particles | Mean concentration (min-max), $\mu g m^{-3}$ | Study organization | Sampling protocol | Ref. |
|--|-----------------------------|--|---|---|--------------------------|
| Exposure risks assessment | PM_{10} | 31 (13–59) | 1 hospital | 24-h PM mass samples; collected during 28 days; constant flow (38.6 L min^{-1}) | Slezakova and Morais (3) |
| Trace metals in size-fractionated particulate matter in a Portuguese hospital | $PM_{2.5}$ $PM_{2.5-10}$ | 23 (11–42) 7.4 (2.5–22) | | | |
| This study investigated IAQ at 39 public sites in southern Taiwan | PM_{10} $PM_{2.5}$ | n.r. (22–90) n.r. (5–35) | 8 hospitals; IAQ study of 39 public places; | 2-min (phase 1) and 24-h (phase 2) PM collection; β -ray decay method | Hsu et al. (4) |
| Long-term surveillance of air quality in medical center operating rooms in 2011 | PM_{10} | n.r. (0.8–55.6) 1 Transplantation room: 10.7 (1.3–37.8) Trauma room: 5.6 (3.2–55.6) Cardiovascular surgery room: 3.0 (0.8–7.8) Colon surgery room: 10.0 (1.6–49.1) Orthopedic surgery room: 12.6 (3.3–31.2) n.r. (0.1–8.4) Transplantation room: 0.9 (0.2–3.1) Trauma room: 1.1 (0.5–8.4) Cardiovascular room: 0.3 (0.1–0.7) Colon surgery room: 0.8 (0.3–2.6) Orthopedic room: | 1 hospital; various operating rooms | PM mass concentrations during 60 min; weakly sampling for 8 consecutive months; light-scattering aerosol analyzer; constant flow (1.2 L min^{-1}) | Wan et al. (86) |
| Hospital indoor $PM_{10}/PM_{2.5}$ and associated trace elements in Guangzhou, China in 2006 | PM_{10} $PM_{2.5}$ | n.r. (n.r.) n.r. (n.r.) | 6 hospitals; IAQ study of 21 public places | Walk-through 2-min samples and during 24-h; β -ray decay method | Wang et al. (57) |
| The acute effects of fine particles on respiratory mortality and morbidity in Beijing in 2013 | PM_{10} $PM_{2.5}$ | 128.13 (61.67–250.00) 99.06 (40.94–214.91) | 4 hospitals | 24-h PM mass samples collected during total of 32 days; low flow samples (5 L min^{-1}) | Wang et al. (87) |
| Measure the indoor air quality in hospital with special emphasis on particulate matter (PM_{10} , $PM_{2.5}$ and $PM_{1.0}$) | PM_{10} $PM_{2.5}$ | 136.36–316.11 (73.38–441.79) 67.28–95.70 (39.55–146.25) | 5 hospitals | 1–2 h continuous PM concentration measurements; light-scattering aerosol analyzer; constant flow (1.2 L min^{-1}) | Verma and Taneja (50) |
| An assessment of indoor $PM_{2.5}$ concentrations at the Cerrahpasa Medical Faculty during the autumn of 2007 between September and December in Istanbul, Turkey | $PM_{2.5}$ | Geriatrics: 18.1 ± 4.5 (8.9–23.1) Nephrology: 23.4 ± 3.3 (16.4–31.4) Cardiology: 37.9 ± 13.3 (18.3–58.5) | Assessment of 1 medical faculty including its hospital and some clinics | 8-h continuous PM concentration measurements during total of 26 workdays; light scattering sensing monitor; logging interval 15 s; constant flow rate | Yurtseven et al. (18) |

Table 2 (continued)

| Location and aim of the study | Particles | Mean concentration (min-max), $\mu\text{g m}^{-3}$ | Study organization | Sampling protocol | Ref. |
|--|-------------------|--|--|---|---------------------|
| Concentrations of $\text{PM}_{2.5}$ mass and components in residential and non-residential indoor microenvironment, USA, 2012 | | n.r. (~2–8) ^a | Residential and non-residential indoor micro-environment; | 7 consecutive days in 2 seasons; 24-h PM mass samples and continuous PM concentrations measurements | Brown et al. (83) |
| Indoor particulate matter measurement as a tool in the process of the implementation of smoke-free hospitals. General hospital, Italy, 2004 | $\text{PM}_{2.5}$ | Operating room: 1.6 ± 0.9 (n.r.) Waiting room: 12.9 ± 1.1 (n.r.) Medical office: 14.8 ± 2.2 (n.r.) | 1 hospital 2 hospitals | 10-h continuous concentration measurements in various hospital areas; laser-operated aerosol mass analyzer; logging interval 2 min | Nardini et al. (88) |
| Second-hand smoke in hospitals in Catalonia (2009): a cross-sectional study measuring $\text{PM}_{2.5}$ and vapor-phase nicotine. L'Hospitalet, Barcelona, Spain, 2010 | $\text{PM}_{2.5}$ | 17.94 (n.r.) Dressing rooms: 8.92 (n.r.) Fire escapes: 34.43 (n.r.) Emergency department room: 16.11 (n.r.) Hall: 18.90 (n.r.) General medicine : 12.46 (n.r.) Cafeteria: 17.59 (n.r.) | 53 hospitals; $\text{PM}_{2.5}$ assessed as marker for ETS; sample collection for 15 min | 15-min $\text{PM}_{2.5}$ concentration samples at each location; light scattering aerosol monitor; constant flow (1.7 L min^{-1}) | Sureda et al. (89) |

^aConcentration range retrieved from plot once precise figures are not given.

Table 3: Average concentration of 11 elements studied in two categories categories, $\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$ at hospital ($\mu\text{g m}^{-3}$).

| | $\text{PM}_{2.5}$ | | $\text{PM}_{2.5-10}$ | |
|--|-------------------|---------------|----------------------|---------------|
| | Average | Concentration | Average | Concentration |
| Al | 98.8 | 46.1–144 | 48.7 | 5.22–244 |
| Si | 145 | 62.2–204 | 175 | 65.1–526 |
| Cl | 406 | 177–591 | 104 | 28–279 |
| Mn | 2.73 | 0.49–5.78 | 0.777 | 0.06–3.53 |
| Se | 0.762 | 0.58–0.89 | 0.139 | 0.12–0.42 |
| Ba | 9.00 | 4.26–18.4 | 16.1 | 2.61–55.4 |
| Cr | 2.14 | 0.85–4.81 | 0.625 | 0.1–2.07 |
| Ni | 3.02 | 0.77–7.74 | 0.506 | 0.07–1/96 |
| As | 80.3 | 39.8–140 | 2.72 | 0.27–99.5 |
| Cd | * | – | * | – |
| Pb | 11.3 | 3.65–20.3 | 0.703 | 0.39–8.75 |
| ΣE_{11} | 759 | 271–1030 | 349 | 134–793 |
| $\bullet\Sigma\text{E}_{\text{total}21}$ | 2890 | 1050–4510 | 1390 | 463–4070 |

● The concentration of all 21 elements detected in the closed environment (36).

*Not detected.

as air conditioning, inadequate building in terms of separation from the outdoor, etc.) (86).

The abundance of other elements in both $\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$ categories is from high to low: barium (2 and 5% of the total 11 elements), manganese (0.4 and 0.2% of the total 11 elements), selenium (0.1 and 0.2% of the total 11 elements) (94). Worrysome carcinogenic elements known by the USEPA as carcinogens of group A include arsenic and chromium. Nickel and lead are also elements that have been identified by the USEPA as group B carcinogens, which are likely to be carcinogens based on studies in animals. The total mean concentration of carcinogens ($\Sigma\text{E}_{\text{carc}}$) of 96.8 and 4.6 in both $\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$ groups are 13% and 1.3% of the total 11 elements, respectively (94).

Specifically, the lead, nickel and chromium content in both PM groups are the lowest. Lead (1 and 0.2% of the total of 11 elements, $\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$, respectively), nickel and chromium (>1 and >0.2% of the total of 11 elements, respectively $\text{PM}_{2.5}$ and $\text{PM}_{2.5-10}$). The concentrations of these three materials are carcinogens which are much lower than the results of a study conducted by Wang et al. in a hospital in Portugal (chromium 15–30 times, nickel 7–13 times and lead 20–30 times) (96). Conversely, the amount of arsenic is the highest in the two PM categories [83% and 60% of the total mean concentration of carcinogens ($\Sigma\text{E}_{\text{carc}}$) in $\text{PM}_{2.5}$ and $\text{M}_{2.5-10}$, for example, 0.8% and 11% of the total of 11 elements] and their level (mean of $\text{PM}_{2.5}$ equal to $80.3 \mu\text{g m}^{-3}$) are almost twice as high as those reported in China (94).

No specific sources of arsenic has been reported in hospitals. In general, arsenic is not commonly a pollutant in

closed environments, however, it can be caused by smoking cigarettes (97). Therefore, smoking was prohibited in hospital environments which was measured and studied. Of course, there was concern about the penetration of fine particles containing artificial arsenic from the outdoor into the building. So far, there is no instruction on the concentration of PM bonded with metals in the indoor environment.

Non-carcinogenic risks associated with inhaling rare element particles were calculated in three different age groups among hospital personnel according to the USEPA method. The mean and target hazard quotient (THQ) for each of the elements in fine PMs were calculated in different age groups of the hospital personnel. The mean THQ estimate for the rare element bonded is from 1.07×10^{-6} for selenium (adults of 55–64 years) to 1.21×10^{-1} for chlorine (adults of 20–24 years).

$$\text{THQ} = (\text{Efr} \times \text{ED} \times \text{ET} \times \text{C} \times \text{IR}) / (\text{RfD} \times \text{BW} \times \text{AT})$$

$$\text{TR} = (\text{Efr} \times \text{ED} \times \text{ET} \times \text{C} \times \text{IUR}) / (\text{AT})$$

THQ and TR are carcinogenic risks and are dimensionless. Efr: exposure frequency (250 days daily) (58). ED: exposure duration (year), ET: exposure time (8 h per day for personnel and 24 h per day for patients) (58), C: metal concentration in air (mg m^{-3}), IR: ingestion rate ($\text{m}^3 \text{day}^{-1}$), BW: body weight (kg), AT: average time (number of days more than standard exposure), RfD: reference doses inhalation ($\text{mg kg}^{-1} \text{day}^{-1}$), IUR: inhalation unit risk (μgm^3) (58). The mean THQ for all of the nine elements in $\text{PM}_{2.5-10}$ shows that THQ 1 is less than 1 for all age groups among hospital personnel ($1 > \text{THQ}$) (86).

Therefore, the risk caused by exposure to non-carcinogenic coarse rare elements was acceptable in all age groups of the hospital personnel. In the case of $\text{PM}_{2.5}$, according to the Se amount, it is equal to 5.88×10^{-6} (55–64 years old) and as to 9.35×10^{-1} (20–24 years old) the risk of more exposure to non-carcinogenic elements was significantly observed. As and Cl (in the next place in terms of abundance) are the most effective (about 90%) elements in non-carcinogenic risk (58).

The total amount of THQ in fine particles is more than the standard for the entire hospital personnel (with the highest percentage in the youth group), in particular, the effects of As and Cl are more than other elements (86).

Effects on susceptible individuals (children, elderly people and patients with underlying diseases)

According to the new science of the International Academy of Sciences (89), new risk assessment methods

are needed to reflect, in an advanced manner, the relationship between exposure and undesirable health effects to modern scientists. For further explanation it can be said that the sensitivity and vulnerability to harmful risk factors strongly varies from one person to another, and will be affected by intrinsic and acquired factors. Some agents associated with intrinsic factors are age, genetics and underlying diseases. Among different stages of human development, people are more sensitive to chemical agents during fetal, infancy, childhood and puberty stages as compared with adults (98). Also, childhood behaviors such as crawling and chewing fingers cause the child to be exposed to more specific environmental chemical agents compared with adults, which is confirmed by studies in this regard (99, 100). Elderly people are also more sensitive than other people to chemical agents such as pollution in the environment (88).

Underlying diseases that affect the functioning of a person's immunity system, such as asthma, coronary heart disease, cardiac arrhythmia and other low-grade anomalies (101) can increase the sensitivity of a person to greater environmental pressures. It is clear that the influence of the risk of environmental chemical agents varies according to genetic variation in different individuals (102). Demographic biological studies on measurable level of chemical agents in each individual in the USA showed that contact with several chemical agents that have the same adverse health effects can have a cumulative effect on the human body and may increase the risk to the individual in the future (103–106). Subsequent to these investigations should be carried out in the hospital environment, on different age and sex group, and susceptible individuals, who are exposed to many chemical substances.

In assessing the effects of contact with chemical agents, according to study in the USA in 2011, two restricting factors make it impossible to properly understand their impact. First, we do not know all the chemicals in the environment or their sources are unknown because there are no standard reports and, in most cases, there is no precise information on how chemicals are produced. Second, after releasing chemical toxic agents to the environment, they may turn into other substances that are also toxic. For example, the use of dichlorodiphenyltrichloroethane (DDT) was banned in 1972. Nowadays, the amount of this material in the human body and environment is much lower than when it was actually used, but one of its by-products called dichloride diphenyl dichloride ethylene (DDE), is still measured in 90% of humans (107). Hence, adverse effect of chemical substances remain for a long time.

To evaluate the ideal risk, the toxicity of by-products can be considered including combustion factors in

manufacturing industries, transportation and energy as well as consumer industries and services, such as water disinfection. That assessment can take 10 years or more. An increase in certain chronic diseases, the potential risk of multiple chemical agents, the large information gap caused by insufficient measurement equipment of chemical agents all require that the methods to manage the chemical agents of the environment should be updated. This is a critical point in preventing many chronic diseases. We can use what we have learned over the past 30 years to set our policies for controlling chemical agents in the next 30 years and then suggest the results obtained decision makers so that they can choose wisely (108). According to studies, it is necessary to control chemical agents for health and prevent many chronic diseases.

Conclusion

The purpose of this review study was to raise awareness on the quality of inhaled air in health care personnel, and to develop appropriate strategies and controllers to protect the medical personnel and visitors to hospital against atmospheric pollutants. Studies show that on the basis of medicines used in emergency room, chemical compounds of drugs create airborne particles containing chemical compounds that care workers inhale daily for long periods of time, exposing them to long-term health hazards (3, 10). When staff are complaining about the poor condition of the air conditioner in a hospital and complaining, for example, that the air is dry or has an unpleasant odour, the ventilation system of the hospital definitely does not work properly. Often, staff complaints and reports in hospital include a number of general symptoms such as tiredness and headache, along with the above mentioned items indicating the problems in the ventilation system in the hospital (62).

According to studies, there are biological and non-biological pollutants in the treatment environment. The amount, concentration and diversity of pollutants vary depending on the type of activity, parts of the hospital (wards) and the drugs and chemical compounds used. Biological pollutants include pathogenic microorganisms and airborne bio-aerosols such as bacteria and spores of fungi that enter the body through inhalation and ingestion. These biological pollutants can intensify the health hazards of personnel and violate the process of recovery from infectious, respiratory, digestive and neuropathic problems.

Based on the conducted studies, non-biological and chemical pollutants include volatile organic and inorganic

compounds, which are rare or toxic in some cases and enter inhaled air from disinfectants such as alcohol (ethanol, isopropanol), aldehydes, detergents, consumables drugs, color and artificial decorations with internal origin, and in some cases of external origin. Particles and gases, according to their nature, can cause health hazards or intensify these effects. Particles in two categories $PM_{2.5}$ and $PM_{2.5-10}$ are airborne particles that can carry organic and toxic components and compounds. In $PM_{2.5}$, the sulfur element is dominant in comparison with other elements, and, respectively, Ni, Cr, As and Pb are more.

The results have proved that (1) the risk of metals in size $PM_{2.5}$ is greater than $PM_{2.5-10}$. (2) Among the carcinogenic elements, the highest risk was observed in the adult age group of 55–64 years old. (3) For all age groups, the greatest risk is related to arsenic. According to the above-mentioned items, the highest risk of cancers caused from $PM_{2.5}$ was observed in the age group of adults aged 55–64 years old, with an amount of 6.10×10.5 (58).

As for carcinogenic elements, according to USEPA considerations, the overall amount 10^{-6} of cancer risk from chemical substances is negligible, however, proposed precautions to ensure the prevention of cancer risk are that all potentially carcinogenic pollutants should not be greater than 10^{-4} (58) because of accumulation in the body.

The minimum amount of arsenic TR in adults of 20–24 years old is 23 times higher than the standard level, which is 10^{-6} , and the maximum observed amount of arsenic is in adults aged 55–64. Both groups are people who have been exposed to arsenic for a long time.

Concerns about the probability of developing cancer are less by inhaling coarse particles of arsenic. The highest risk is for the 55–64 age groups, with TR for arsenic about twice as many as 10^{-6} .

Chromium is the second most effective agent for hospital personnel who are at risk of carcinogenic exposure to inhaled hospital personnel. Inhalation of hexavalent chromium with a ratio of 1–6 (chromium 3–6) is considered.

In $PM_{2.5}$ particles, TR arsenic is 2 to 5 times higher than the USEPA standard for all age groups in the hospital personnel. By assessing all age groups in hospital personnel, $PM_{2.5}$, TR for nickel and lead is 4–11 and 41–113 times lower than the threshold (10^{-6}). While for $PM_{2.5-10}$, for nickel and lead it is equal to 23–63 and 662–1820 times, respectively. Due to the synergistic effect of particles and rare elements, the estimated risk may be higher than this limit (80).

Analysis of health risks to personnel have been performed according to the USEPA standard (57). Repeated exposure is considered to be 250 days a year (5 days, 50 weeks) and 8 h per week (e.g. 40 h per week); however,

the workload of the specialist personnel of the medical staff is more than this amount (95), and work hours are longer. In some specialized occupations, such as general surgeons or anesthesiologists, they work more than 60 h a week (96). Therefore, the exposure risk is higher than the amount estimated here. Particularly in radiologists who have been working 58 h a week (97).

In general, in order to identify the potentials of health risk included in contact with chemical and biological pollutants, first the scale and complexity of the evaluation and its outcome should be stated.

In the absence of complete information, related health risks should be described, decisions are made based on the structure of chemical substances and other chemical toxicity indicators.

The most important issue is that commercial, economic, and political considerations do not interfere in the assessment of health risks. The cost of managing health risks does not affect risk magnification, but it may affect the choice of risk management methods.

Studying the ways a chemical agent affects in terms of toxicity in accession of certain biological events leads to a quicker evaluation of the identification of different types of chemical compounds, although the probability of uncertainty will be very high in this assessment. Absolute safety or the absence of any health risks in dealing with chemical agents in the environment is an idealistic and non-scientific issue. Therefore, it is imperative that common methods are modified to make scientific decisions.

Considering that human activities in different parts of a hospital and type of ventilation system are two factors that are very effective on air quality, the conditions and sources of pollutant production should be considered and appropriate ventilation systems should be used.

The ratio of indoor/outdoor pollutant concentrations (I/O) is a factor that can be used to determine the source of pollutants and the type of ventilation system efficiently. If the concentration of pollutants in indoor air is more than 1 in relation to the outdoor air ($I/O > 1$), natural and mechanical ventilation can reduce the amount of pollutants in the indoor air. In the case of biological agents and Na and Ca elements at hospital, this is the case. But if ($I/O < 1$), because the source of the pollutant is mainly outside the building, natural ventilation is not effective in reducing pollutant concentrations and mechanical ventilation can reduce pollutant concentrations to a standard level. In the case of BC and $PM_{2.5}$, this is the case.

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